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**Huang et al.**

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(54) **METHOD OF PROGRAMMING A MULTI-BIT PER CELL NON-VOLATILE MEMORY**

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**G11C 16/04** (2006.01)

(52) **U.S. Cl.**  
USPC ..... **365/185.03**; 365/185.2; 365/185.22;  
365/185.28

(58) **Field of Classification Search**  
USPC ..... 365/185.03, 185.2, 185.22, 185.28  
See application file for complete search history.

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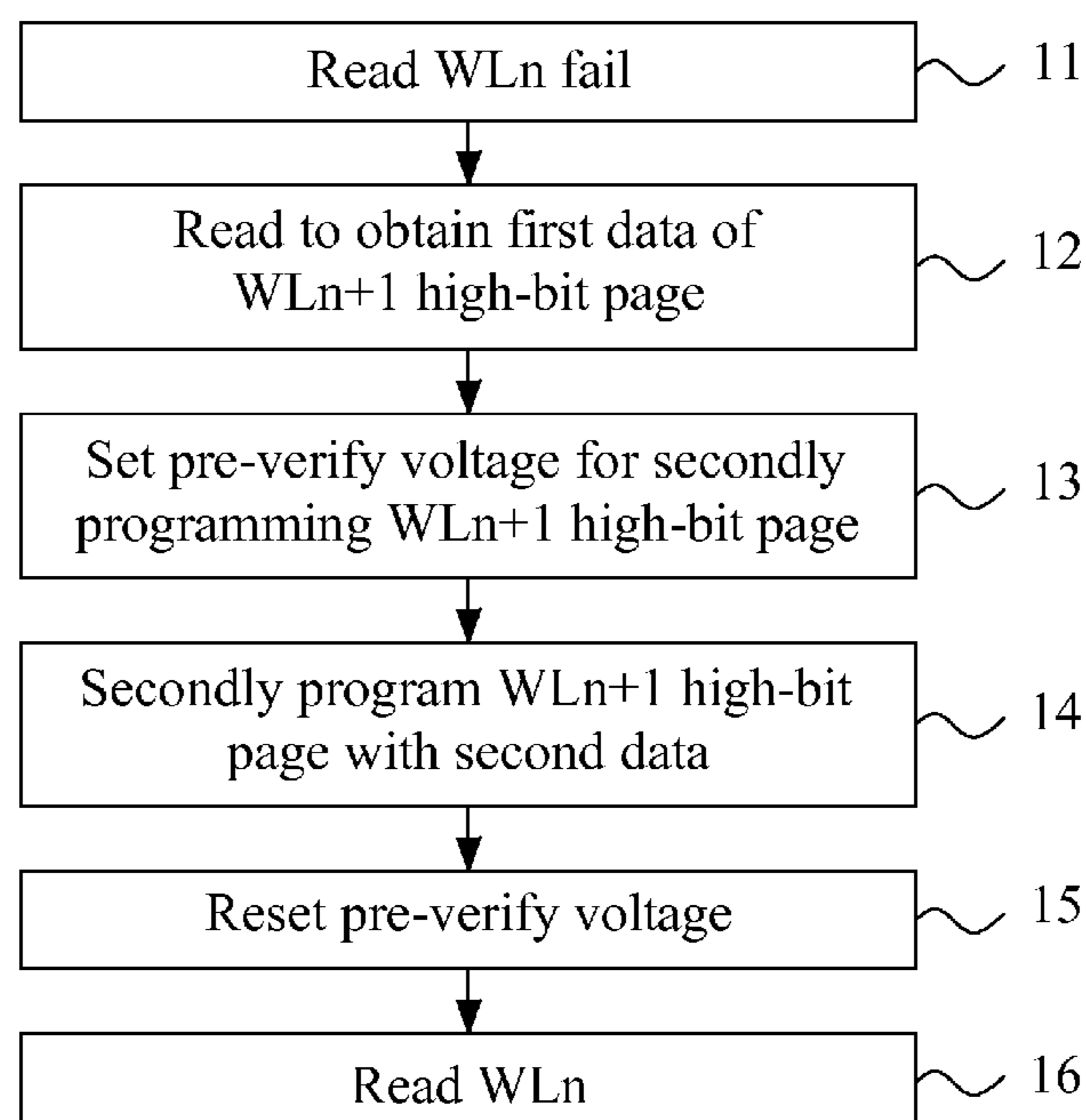
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(57) **ABSTRACT**

A method of programming a multi-bit per cell non-volatile memory is disclosed. In one embodiment, the non-volatile memory is read to obtain a first data of a most-significant-bit (MSB) page on a current word line that succeeds in data reading, wherein the current word line follows a preceding word line on which data reading fails. At least one reference voltage is set. The MSB page on the current word line is secondly programmed with a second data according to the reference voltage, the second data being different from the first data.

**9 Claims, 13 Drawing Sheets**



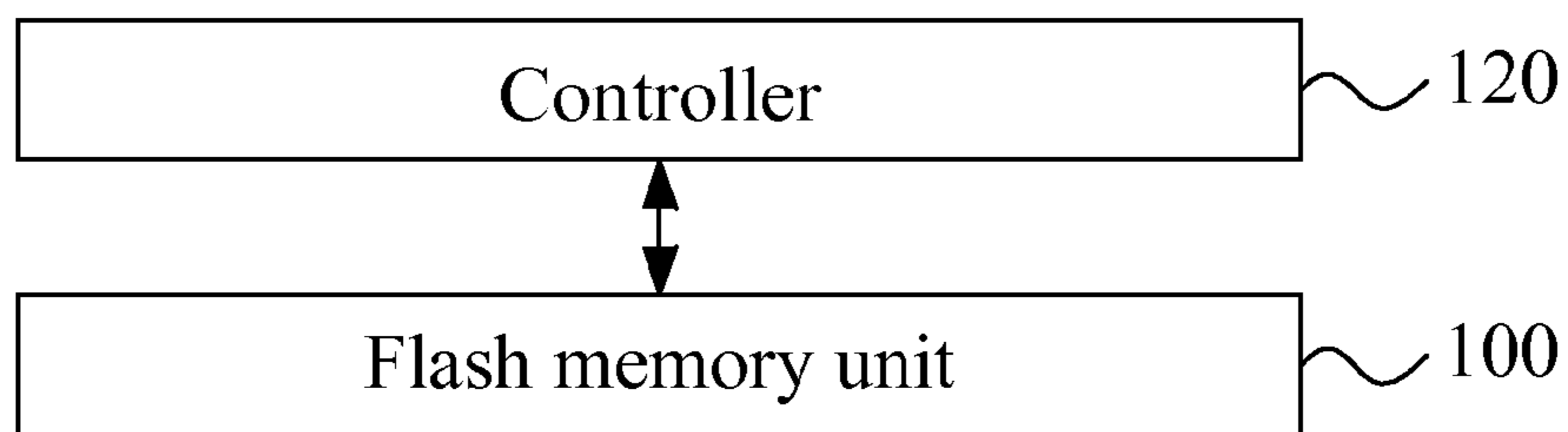


FIG. 1A

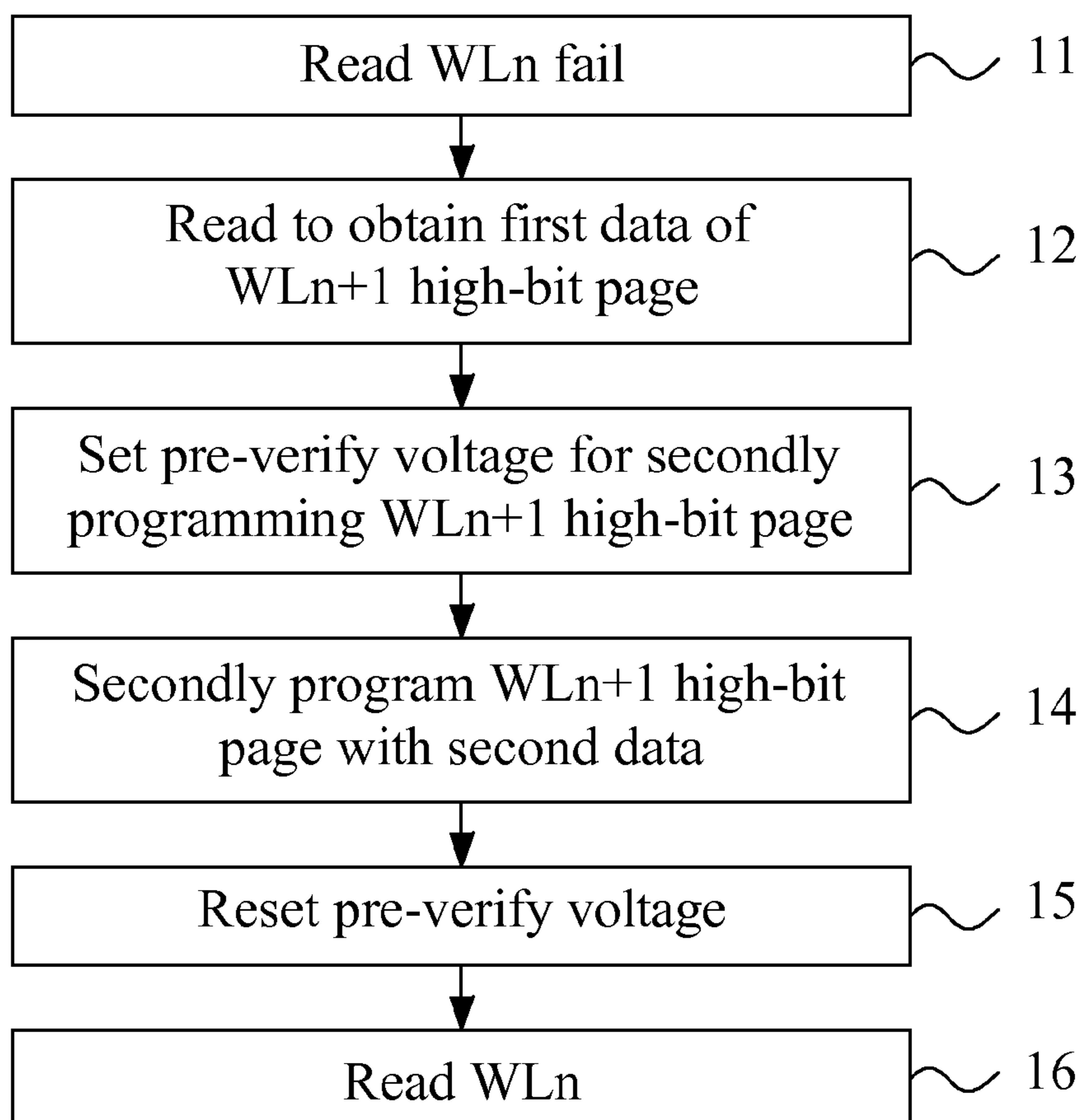


FIG. 1B

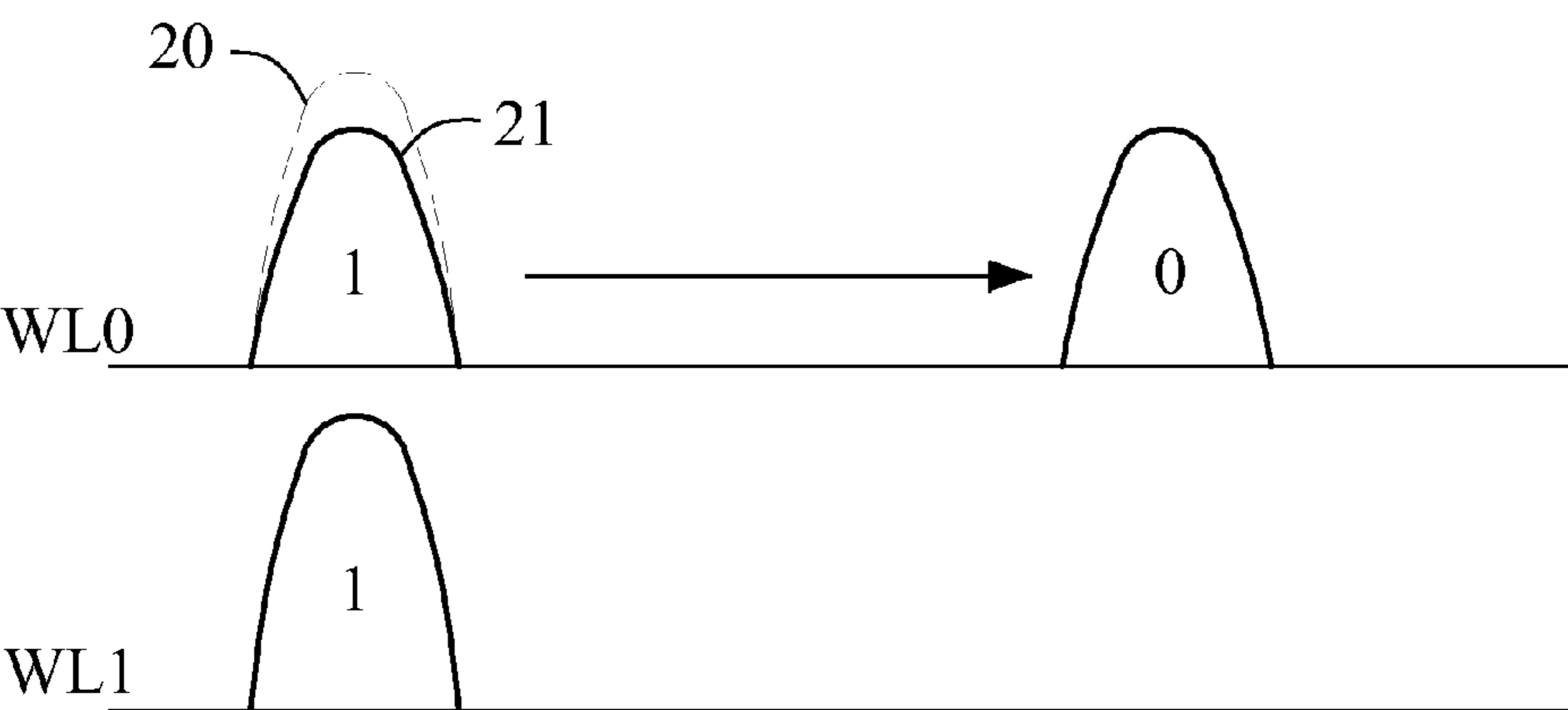


FIG. 2A

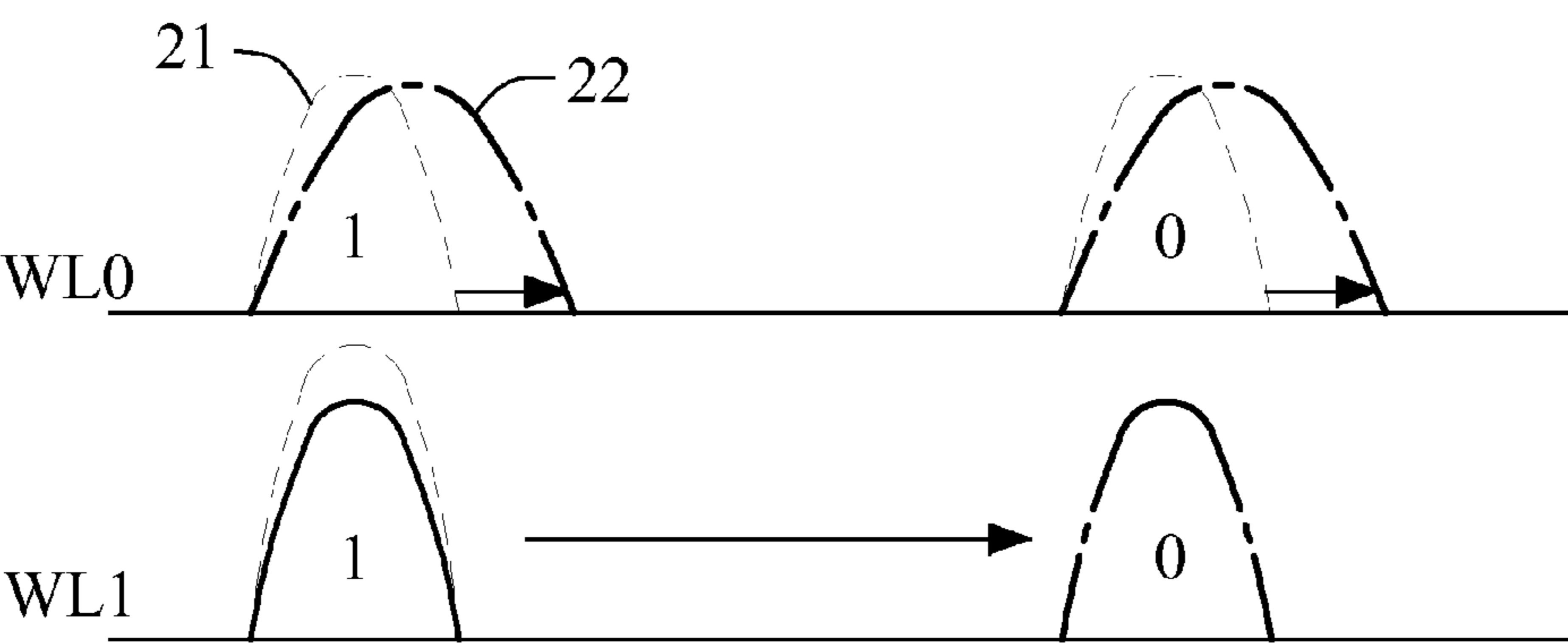


FIG. 2B

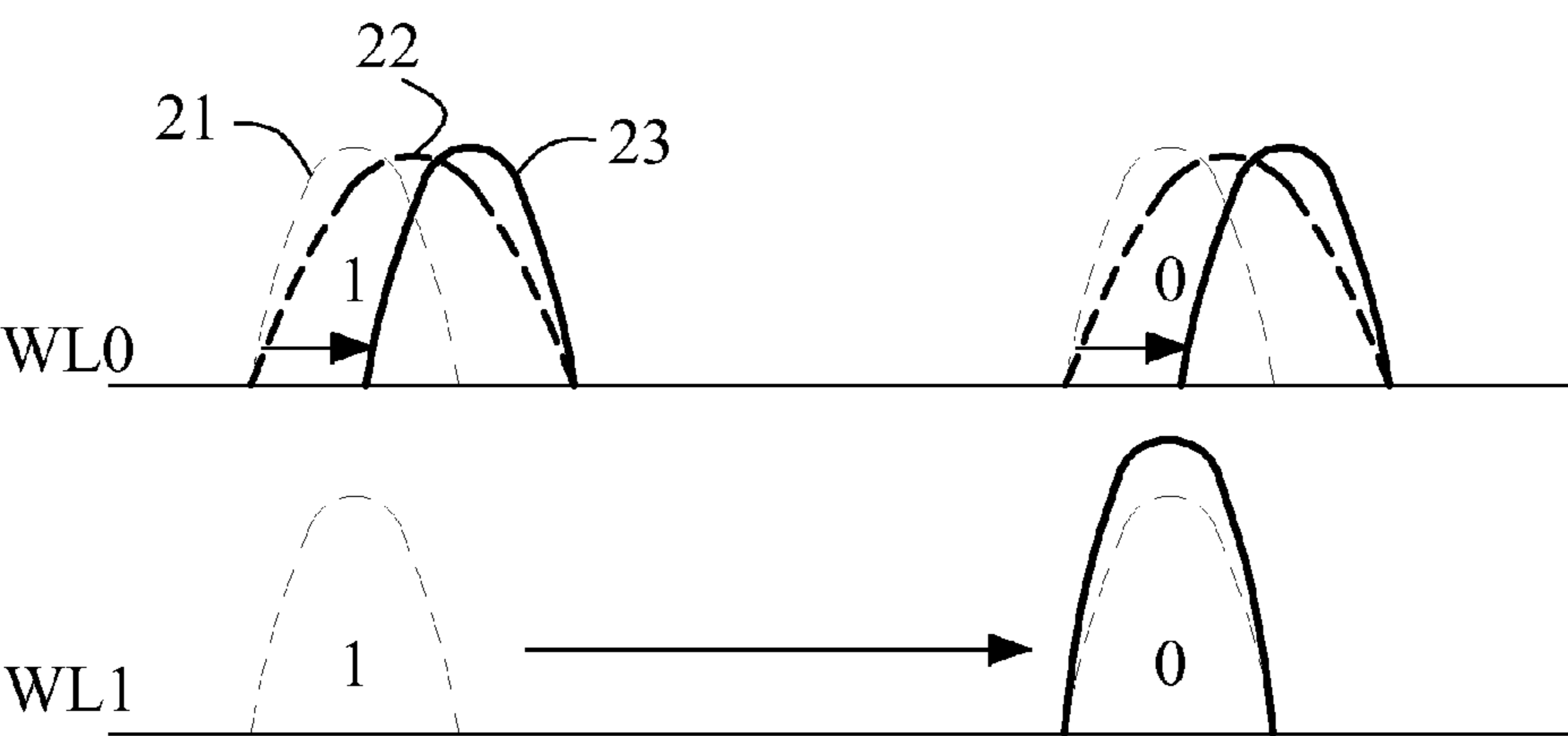


FIG. 2C

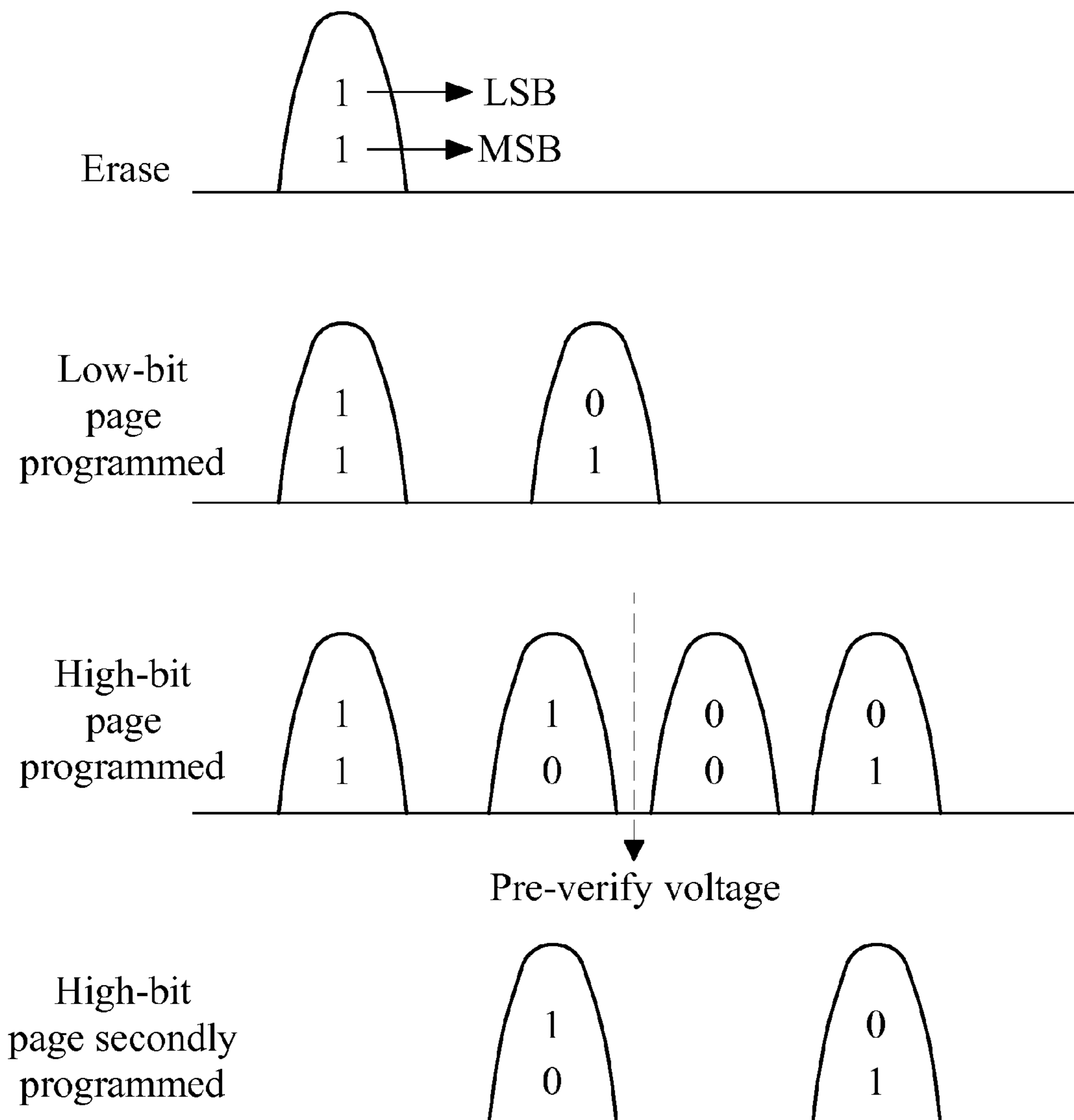


FIG.3

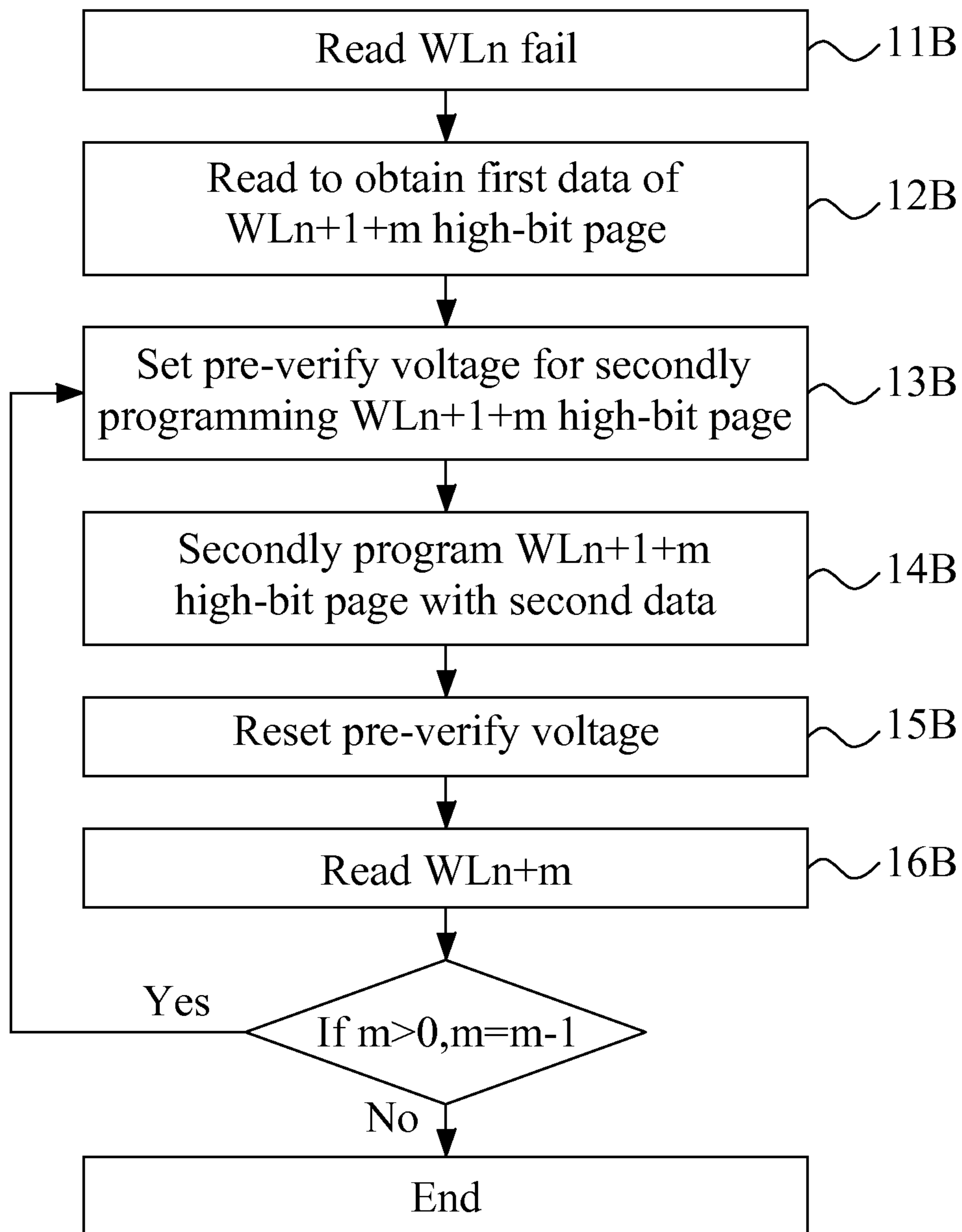


FIG.4

	t1 Read	t2	t3	t4
WL0(Block 1st)				
WL1				
WL2				
WL3				
• • • • •				
WLn	Fail			re-read
WLn+1	Fail		re-read	re-program
• • • • •	Fail	re-read	re-program	
WLn+1+m	Pass	re-program		
WLn+2+m	Pass			
• • • • •				
WLz(Block last)				

FIG.5A

	t1 Read	t2	t3	t4
WL0(Block 1st)				
WL1				
WL2				
WL3				
• • • • •				
WLn	Fail			re-read
WLn+1	Fail		re-read	re-program
• • • • •	Fail	re-read	re-program	
WLn+1+m(Block last)	Pass	re-program		

FIG.5B

	Low-bit page(LSB)	High-bit page(MSB)
WL0	00	02
WL1	01	04
WL2	03	06
WL3	05	08
• • • •		
WL61	79	7C
WL62	7B	7E
WL63	7D	7F

FIG.6

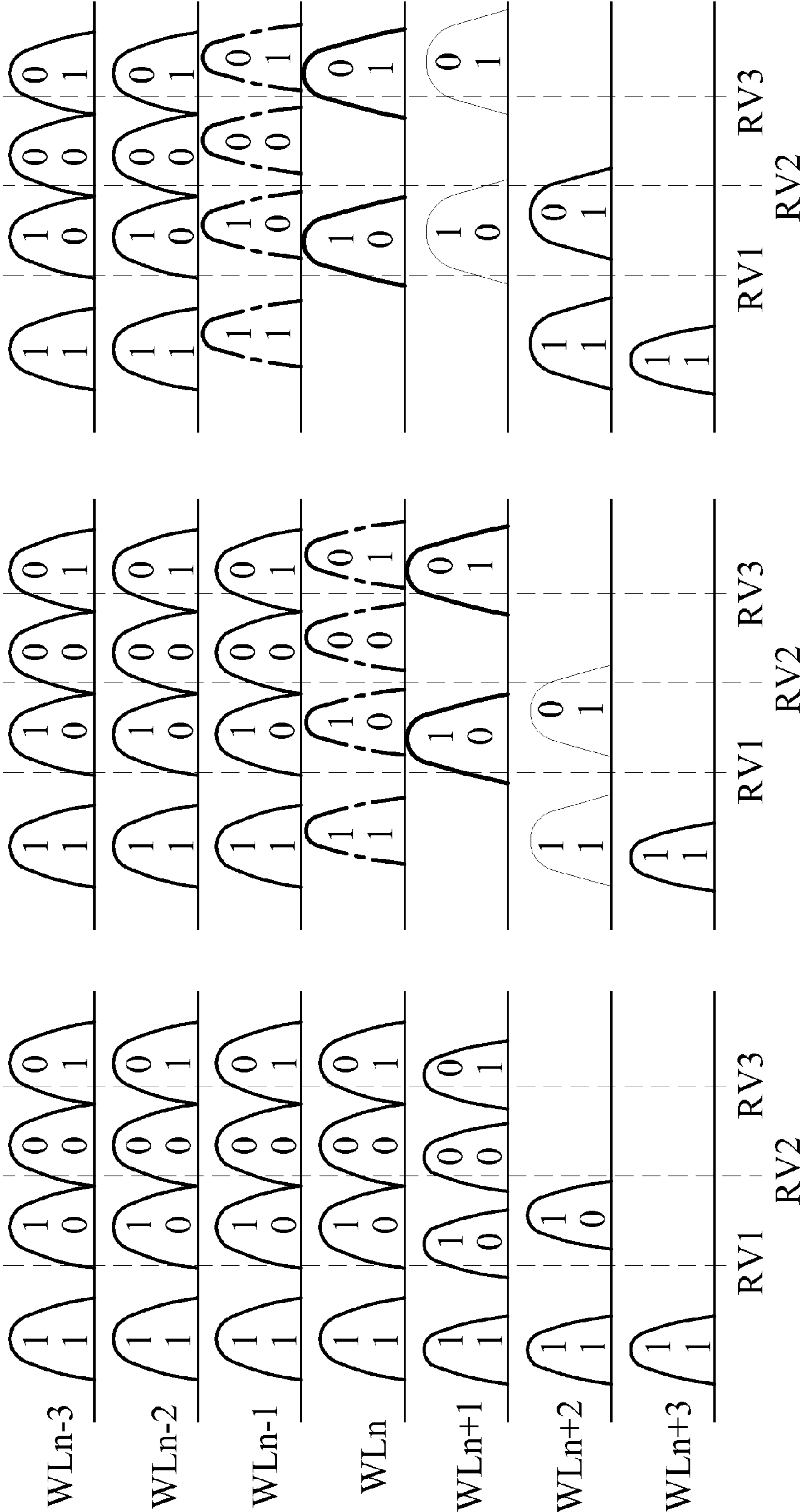


FIG. 7A

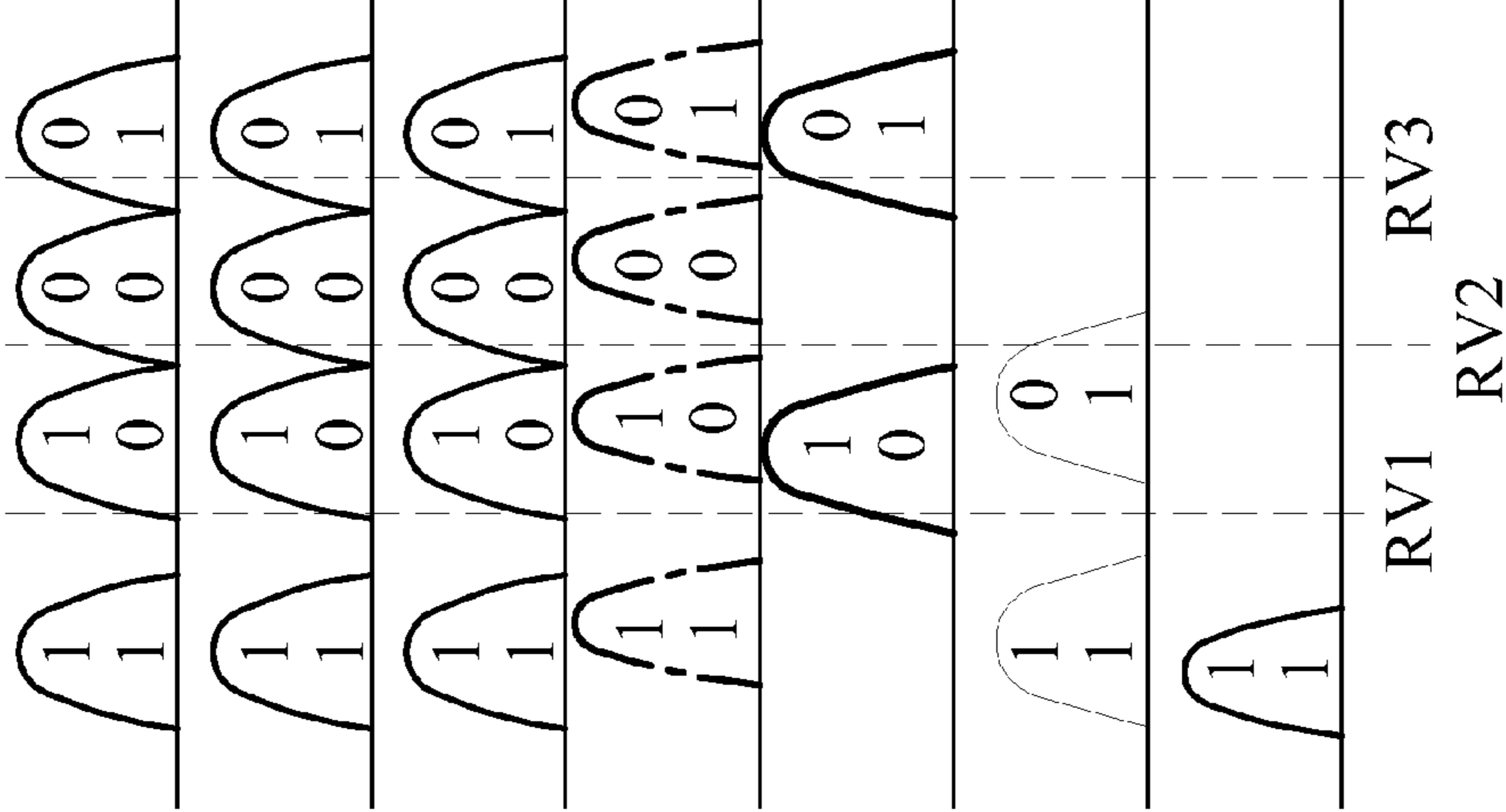


FIG. 7B

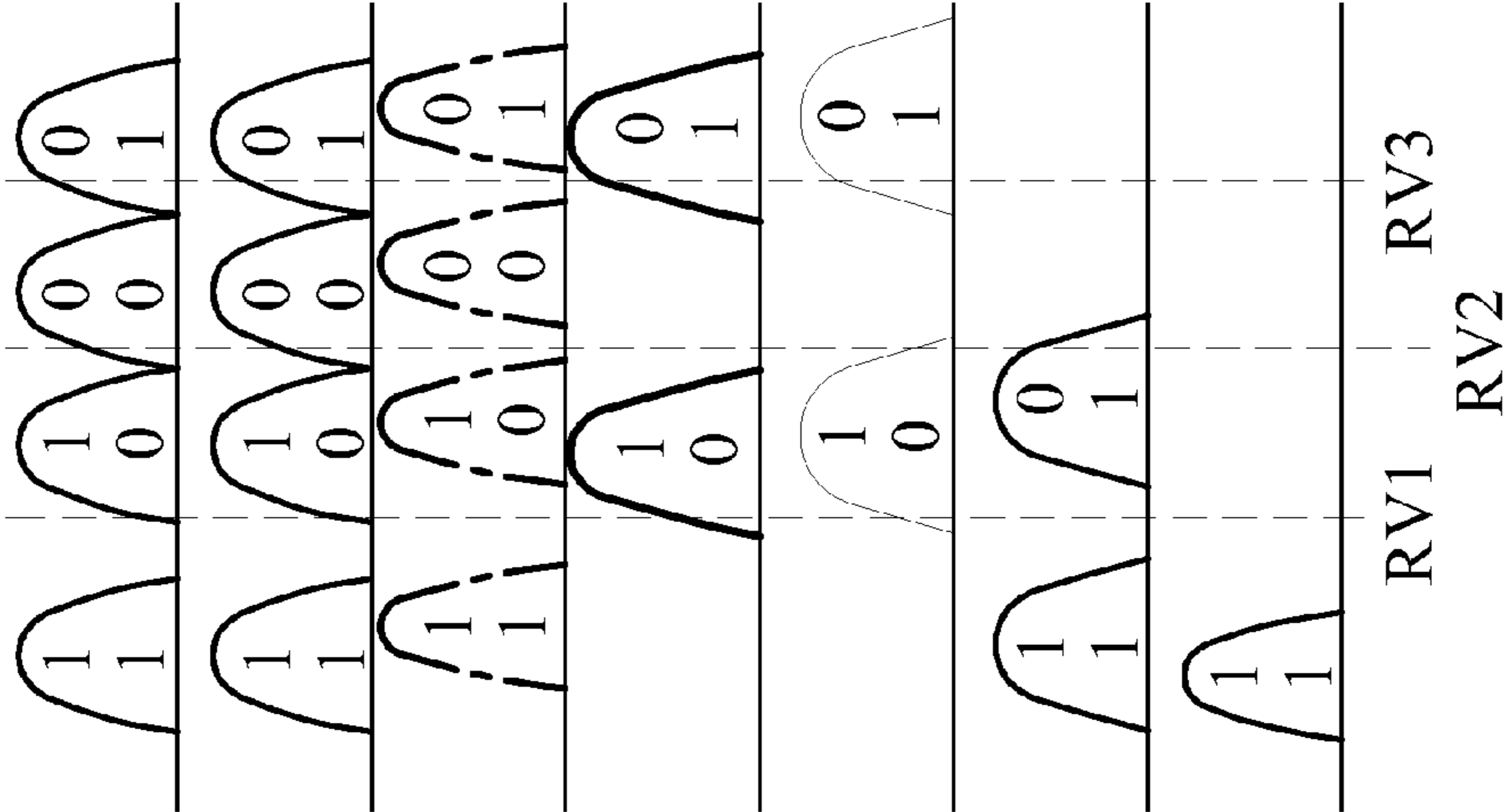


FIG. 7C

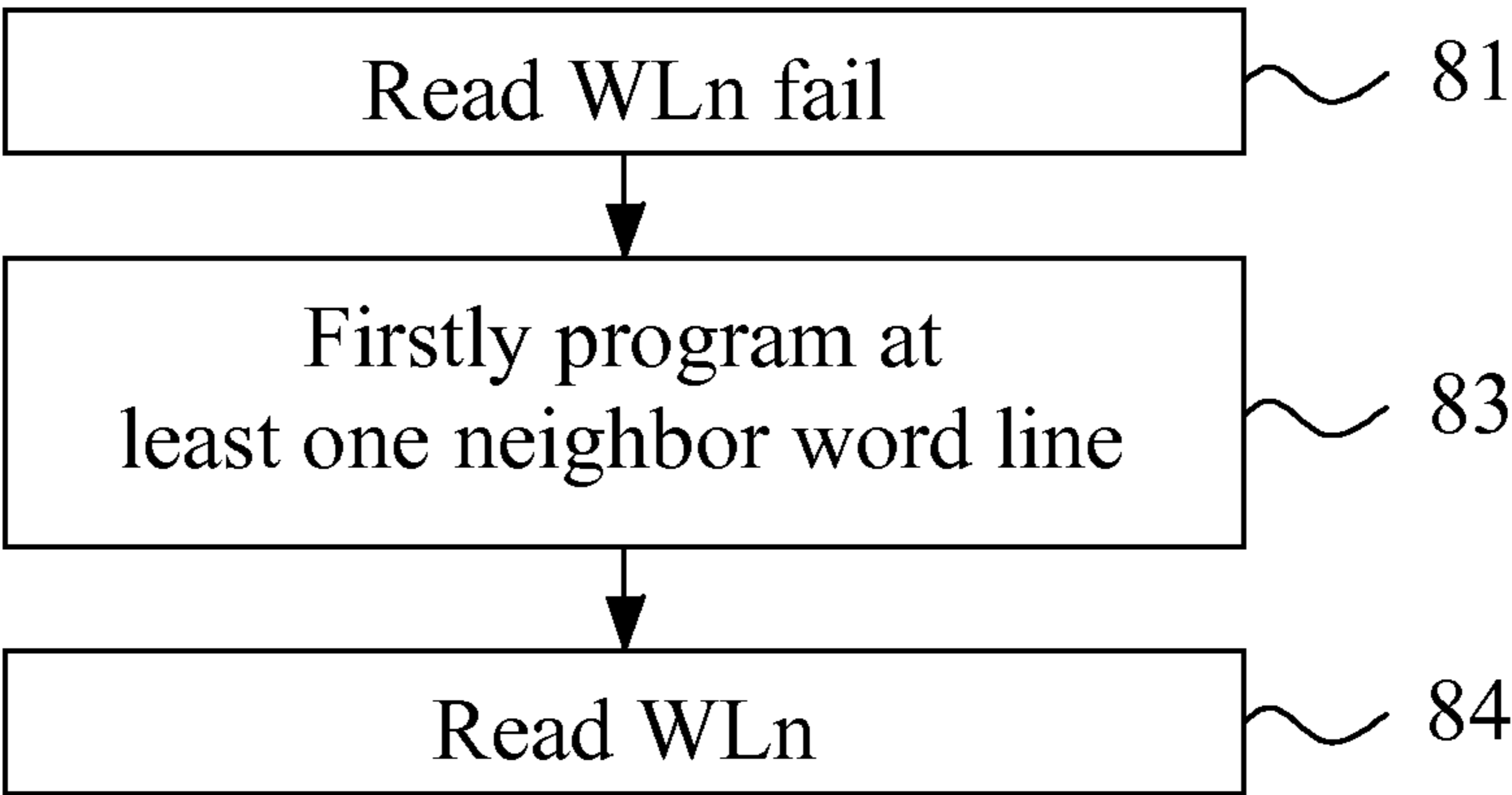


FIG.8A

	LSB	CSB	MSB
WL0	0	2	5
WL1	1	4	8
WL2	3	7	11
WL3	6	10	
WL4	9		

FIG.8B

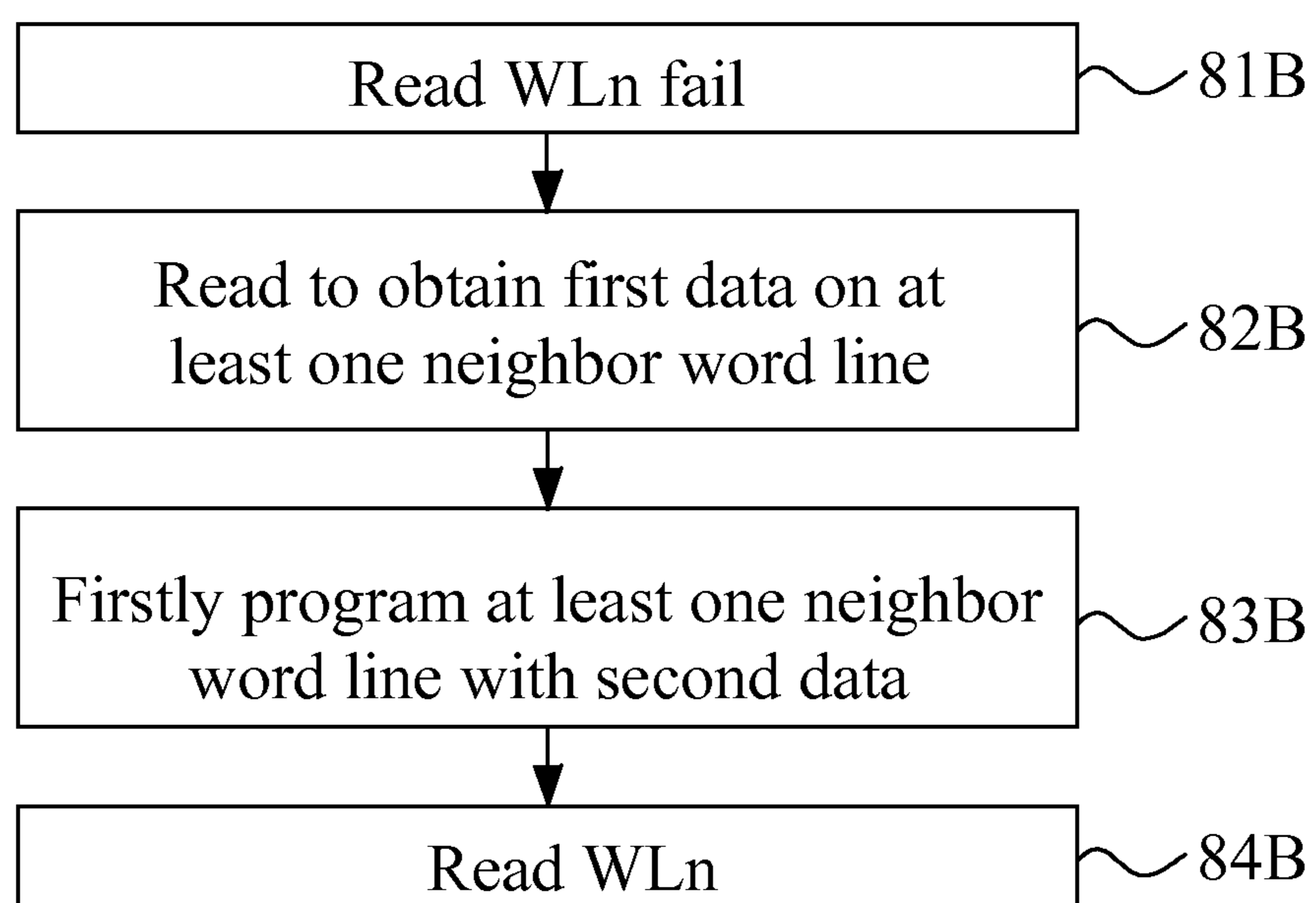


FIG.8C

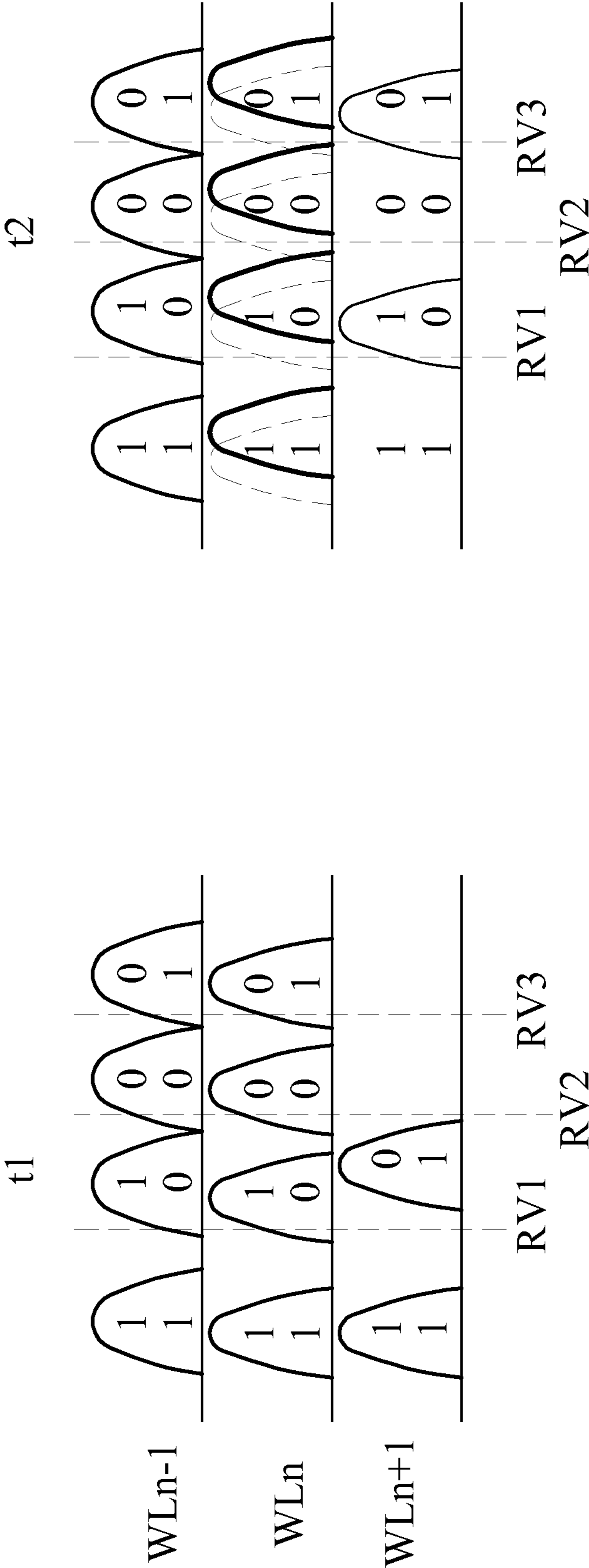


FIG. 9A

FIG. 9B

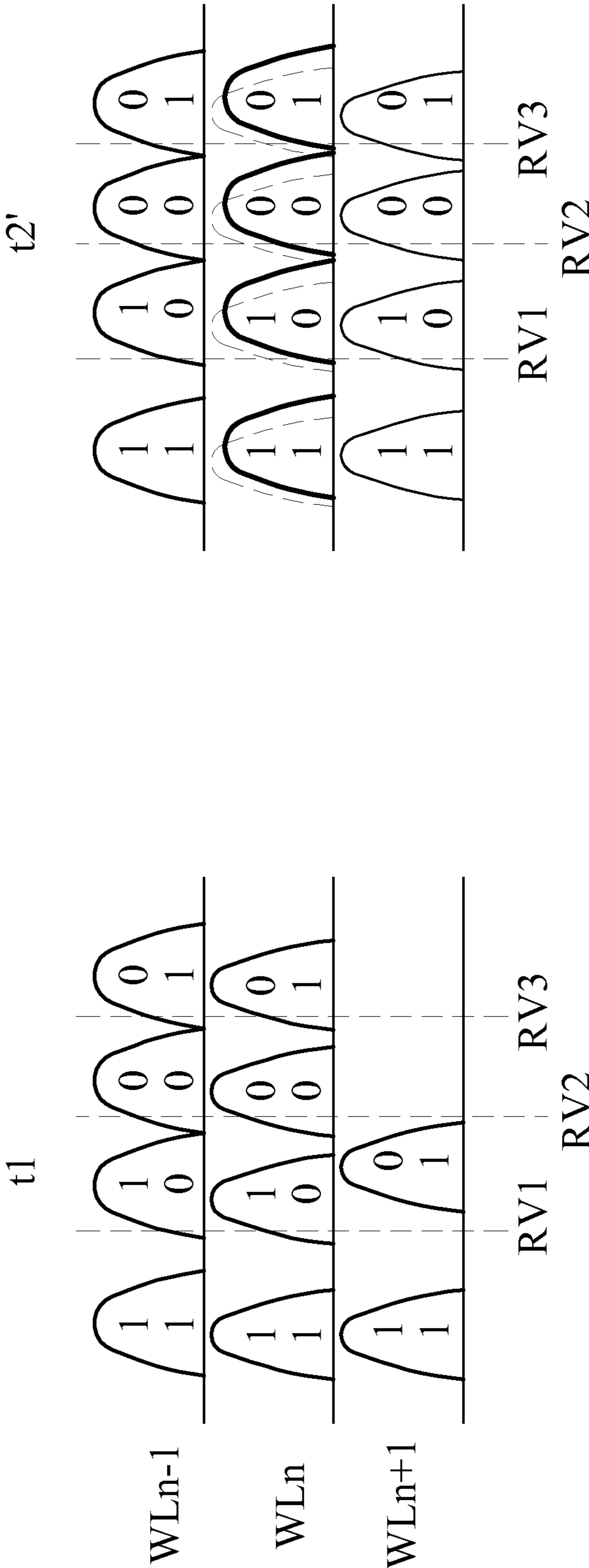


FIG.9C

FIG.9D

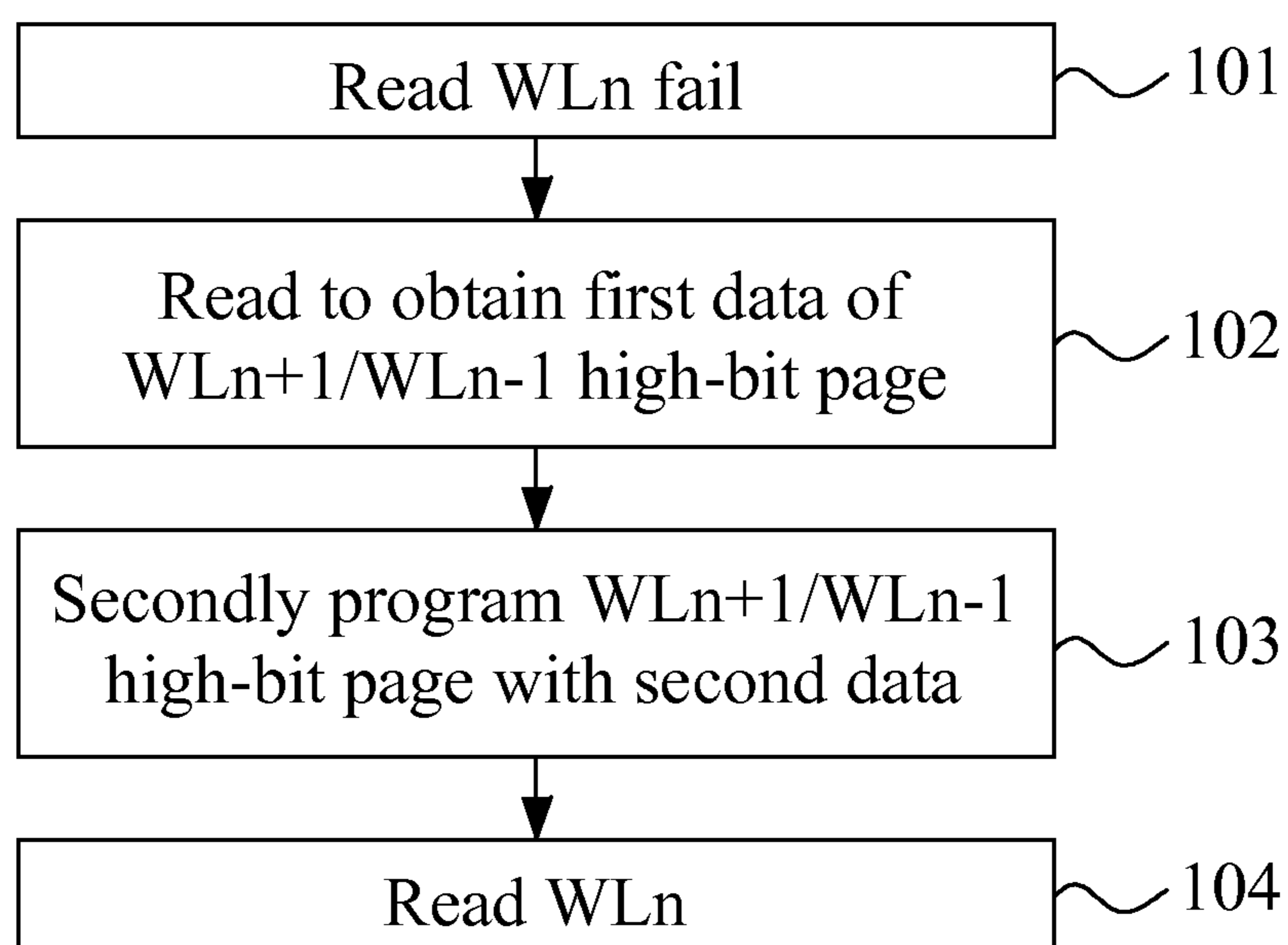


FIG.10

## 1

**METHOD OF PROGRAMMING A MULTI-BIT  
PER CELL NON-VOLATILE MEMORY****BACKGROUND OF THE INVENTION****1. Field of the Invention**

The present invention generally relates to a non-volatile memory, and more particularly to a method of programming a multi-bit per cell non-volatile memory for improving coupling effect.

**2. Description of Related Art**

Flash memory is a non-volatile solid state memory device that can be electrically erased and reprogrammed. A conventional flash memory stores a single bit of information in each memory cell such that each memory cell can be programmed to assume two possible states. The conventional flash memory is thus commonly referred to as a single-bit per cell flash memory. A modern flash memory is capable of storing two or more bits of information in each memory cell such that each memory cell can be programmed to assume more than two possible states. The modern flash memory is thus commonly referred to as a multi-bit per cell flash memory.

In the multi-bit per cell flash memory, data of different state are programmed to the flash memory by storing different amount of charge in the floating gate of the flash memory. As the charge in the floating gate specifically determines the corresponding threshold voltage, the data can thus be read from the multi-bit per cell flash memory according to their different threshold voltages. Due to variations among the memory cells during the manufacture or operation, the threshold voltage of each state is not a constant value but a range.

However, the conventional multi-bit per cell flash memory, particularly the three-bit per cell or even more-bit per cell flash memory, suffers from floating-gate coupling effect and retention effect. As a result, the conventional multi-bit per cell flash memory could probably result in read errors due to narrow read margin, and a need has thus arisen to propose some novel schemes to improve floating-gate coupling effect.

**SUMMARY OF THE INVENTION**

In view of the foregoing, it is an object of the embodiment of the present invention to provide a method of programming a multi-bit per cell non-volatile memory for improving coupling effect to increase read margin, thereby reducing read errors.

According to one embodiment, a multi-bit per cell non-volatile memory is read to obtain a first data of a most-significant-bit (MSB) page on a current word line that succeeds in data reading, wherein the current word line follows at least one preceding word line on which data reading fails. At least one reference voltage is set. The MSB page on the current line is secondly programmed with a second data according to the reference voltage, the second data being different from the first data.

According to another embodiment, data is read on a current word line on which the data reading fails. At least one neighbor word line is firstly programming, wherein page or pages to be firstly programmed have program sequence numbers after the program sequence number of a failed page of the failed current word line.

According to a further embodiment, a multi-bit per cell non-volatile memory is read to obtain a first data of a most-significant-bit page on at least one neighbor word line that is neighboring to a current word line on which data reading fails. The most-significant-bit page is secondly programmed with a

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second data on the at least one neighbor word line, the second data being different from the first data.

**BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1A schematically shows a simplified block diagram of a non-volatile memory system according to one embodiment of the present invention;

FIG. 1B shows a flow diagram of a method of programming a multi-bit per cell nonvolatile memory for improving coupling effect according to a first embodiment of the present invention;

FIG. 2A to FIG. 2C show exemplary threshold voltage (VT) distributions on neighboring word lines WL0 and WL1 illustrative of coupling effect and coupling effect cancellation by twice programming;

FIG. 3 shows exemplary threshold voltage distributions of a 2-bit per cell flash memory;

FIG. 4 shows a flow diagram of a method of programming a multi-bit per cell non-volatile memory for improving coupling effect according to an alternative embodiment of FIG. 1B;

FIG. 5A and FIG. 5B show examples associated with the flow of FIG. 4;

FIG. 6 shows a program/read sequence in a memory block for a 2-bit per cell flash memory;

FIG. 7A to FIG. 7C show exemplary threshold voltage distributions of a 2-bit per cell flash memory according to the program/read sequence shown in FIG. 6;

FIG. 8A shows a flow diagram of a method of programming a multi-bit per cell non-volatile memory for improving coupling effect according to a second embodiment of the present invention;

FIG. 8B shows an exemplary program sequence for a 3-bit per cell flash memory;

FIG. 8C shows a flow diagram of a method of programming a multi-bit per cell non-volatile memory for improving coupling effect according to an alternative embodiment of FIG. 8A;

FIG. 9A and FIG. 9B show exemplary threshold voltage distributions without using the pre-verify voltage;

FIG. 9C and FIG. 9D show some other exemplary threshold voltage distributions without using the pre-verify voltage; and

FIG. 10 shows a flow diagram of a method of programming a multi-bit per cell non-volatile memory for improving coupling effect according to a third embodiment of the present invention.

**DETAILED DESCRIPTION OF THE INVENTION**

FIG. 1A schematically shows a simplified block diagram of a non-volatile memory system such as a flash memory according to one embodiment of the present invention. Other non-volatile memory may, for example, be a phase change memory (PCM) or an electrically erasable programmable read-only memory (EEPROM). In the embodiment, the flash memory includes a flash memory unit **100**, particularly a multi-bit per cell NAND flash memory unit. The flash memory system also includes a controller **120** that is capable of twice programming the flash memory unit **100**. The controller **120** may be implemented by hardware circuitry, software or their combination.

FIG. 1B shows a flow diagram of a method of programming a multi-bit per cell non-volatile memory for improving coupling effect according to a first embodiment of the present invention.

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In step 11, data reading fails on an n-th word line  $WLn$  of the flash memory when the data cannot pass an error control. Subsequently, in step 12, the flash memory is read to obtain a first data of a high-bit page (or most-significant-bit page or MSB page) on a following  $(n+1)$ -th word line  $WLn+1$ , which is assumed to succeed in data reading. Next, in step 13, at least one reference voltage (RV) such as a pre-verify voltage for secondly programming the high-bit page on the word line  $WLn+1$  is set. Details of twice programming a non-volatile memory may be referred to in U.S. patent application Ser. No. 12/831,612, filed on Jul. 7, 2010, entitled "Method of Twice Programming a Non-Volatile Memory with a Sequence" assigned to the same assignee of the present application, the disclosure of which is hereby incorporated by reference. Afterwards, in step 14, the high-bit page on the word line  $WLn+1$  secondly programmed with a second data according to the pre-verify voltage that is set in step 13. In the embodiment, the second data not the same as, and preferably is an inverse of, the first data. In the embodiment, the term "inverse" means that data bit of the first data is the opposite of the data bit of the second data. For example, the inverse of bit "1" is "0" and vice versa. According to the embodiment, the twice programming the high-bit page on the word line  $WLn+1$  may substantially improve the coupling effect on the preceding word line  $WLn$  and thus increase its read margin. In step 15, the pre-verify voltage is reset to the pre-verify voltage prior the step 13. Finally, in step 16, the word line  $WLn$ , which fails the data reading in step 11, of the flash memory is read again. As the read margin on the n-th word line  $WLn$  is increased, data reading on the preceding word line  $WLn$  will succeed.

FIG. 2A to FIG. 2C show exemplary threshold voltage (VT) distributions on neighboring word lines  $WL0$  and  $WL1$  illustrative of coupling effect and coupling effect cancellation by twice programming. Specifically, FIG. 2A shows VT distributions after  $WL0$  is programmed, where the curve 20 represents the VT distribution after erase and the curve 21 represents the VT distribution after  $WL0$  is programmed. FIG. 2B shows VT distributions after  $WL1$  is programmed. The programming  $WL1$  incurs coupling effect on  $WL0$ , and thus makes the resultant distribution 22 on  $WL0$  extended in range, thereby decreasing read margin for  $WL0$ . FIG. 2C shows VT distributions after  $WL1$  is secondly programmed. The secondly programming  $WL1$  makes the VT distribution 23 on  $WL0$  decreased in range, thereby increasing the read margin for  $WL0$ . It is observed, that the resultant VT distribution 23 on  $WL0$  has substantially the same, but shifted, VT distribution as the VT distribution 21 prior being affected by the coupling effect.

FIG. 3 shows exemplary threshold voltage distributions of a 2-bit per cell flash memory with respect to a state after erase, after programming a low-bit page, after programming a high-bit page and after secondly programming the high-bit page, respectively. Specifically, the high-bit page is secondly programmed with an inverse data according to a new pre-verify voltage.

FIG. 4 shows a flow diagram of a method of programming a multi-bit per cell non-volatile memory for improving coupling effect according to an alternative embodiment of FIG. 1B.

In step 11B, data readings fail on some word lines beginning at an n-th word line  $WLn$  of the flash memory. Subsequently, in step 12B, the flash memory is read to obtain a first data of the high-bit page on at least one word line that succeeds in data reading, such as the word lines  $WLn+1+m$  in FIG. 5A or the last word line  $WLn+1+m$  in FIG. 5B. Next, in step 13B, the pre-verify voltages for secondly programming the high-bit page on the word line  $WLn+1+m$  is set. After-

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wards, in step 14B, the high-bit page on the word line  $WLn+1+m$  is secondly programmed with a second data according to the pre-verify voltage that is set in step 13B. In the embodiment, the second data is not the same as, and preferably is an inverse of, the first data. The first data preferably is a most-significant-bit (MSB) page data on the word line  $WLn+1+m$ . In step 15B, the pre-verify voltage is reset to the pre-verify voltage prior the step 13B. In step 16B, the word line  $WLn+m$ , which fails the data reading in step 11B, of the flash memory is read again. As the read margin on the word line  $WLn+m$  is increased due to secondly programming the word line data reading on the preceding word line  $WLn+m$  will succeed. Steps 13B to 16B are repeated until all the word lines that fail data readings are successfully re-read as shown in FIG. 5A or FIG. 5B. Further, the data read from the word line  $WLn+1+m$ , or plus additionally to read a data from the word line  $WLn+2+m$ , may be backup to other word lines before secondly programming the word line  $WLn+1+m$ .

FIG. 6 shows a program/read sequence in a memory block for a 2-bit per cell flash memory. FIG. 7A to FIG. 7C show exemplary threshold voltage distributions of a 2-bit per cell flash memory according to the program/read sequence shown in FIG. 6. Specifically, FIG. 7A shows the VT distributions at a time that a low-bit page on word line  $WLn+2$  is programmed, followed by programming a high-bit page on word line  $WLn+1$ . Subsequently, as shown in FIG. 7B, the high-bit page on the word line  $WLn+1$  is secondly programmed with inverse data, thereby increasing read margin on the word line  $WLn$ . Similarly, as shown in FIG. 7C, the high-bit page on the word line  $WLn$  is secondly programmed with inverse data, thereby increasing read margin, on the word line  $WLn-1$ .

It is noted that, in some circumstances, the pre-verify voltage setting step 13/13B as discussed above may possibly or unsuitably be performed. Accordingly, the embodiment as illustrated in FIG. 1B or FIG. 4 may be modified to accommodate this situation. FIG. 8A shows a flow diagram of a method of programming a multi-bit per cell non-volatile memory for improving coupling effect according to a second embodiment of the present invention. Specifically, in step 81, data reading fails on a current word line  $WLn$  of the flash memory when the data cannot pass an error control. Afterwards, in step 83, at least one neighbor word line is firstly programmed, for example, with random data that is randomly generated; uniformly distributed data that have 0s of the amount approximately equal to the amount of 1s; or same data of 0s or 1s. The at least one neighbor word line may be the word line(s) succeeding the word line  $WLn$  and/or the word line(s) preceding the word line  $WLn$ . Finally, in step 84, the word line  $WLn$ , which fails the data reading in step 81, of the flash memory is read again.

In a preferred embodiment, the page or pages to be firstly programmed in step 83 have program sequence numbers after the program sequence number of the failed page of the current word line  $WLn$  in step 81. FIG. 8B shows an exemplary program sequence for a 3-bit per cell flash memory. It is assumed that pages 0-6 have been programmed, and data reading fails on a center-significant bit (CSB) page (i.e., page 4) of word line 1. In order to improve the coupling effect, the CSB page (i.e., page 7) having the program sequence number after the page 4, on the succeeding word line  $WL2$  is firstly programmed. In another example, it is assumed that pages 0-6 have been programmed, and data reading fails on an MSB page (i.e., page 5) of word line 0. In order to improve the coupling effect, an MSB page (i.e., page 8) on the succeeding word line  $WL1$  may be firstly programmed. Alternatively, page 7 and page 8 on the succeeding word lines  $WL1$  and  $WL2$  may be firstly programmed to improve the coupling

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effect. In a further example, it is assumed that pages 0-7 have been programmed, and data reading fails on a CSB page (i.e., page 7) of word line 2. In order to improve the coupling effect, the MSB page (i.e., page 8) having the program sequence number after the page 7, on the preceding word line WL1 is firstly programmed.

FIG. 8C shows a flow diagram of a method of programming a multi-bit per cell nonvolatile memory for improving coupling effect according to an alternative embodiment of FIG. 8A. Specifically, in step 81B, data reading fails on a current word line WLn of the flash memory when the data cannot pass an error control. Subsequently, in step 821B, the flash memory is read to obtain a first data of a less-significant-bit page (e.g., low-bit page or least-significant-bit (LSB) page) or a center-significant bit (CSB) page on at least one neighbor word line. Generally, the first data is read from a page has been programmed on the at least one neighbor word line. Afterwards, in step 83B, one page of the at least one neighbor word line is firstly programmed with a second data that is different from the first data. In one embodiment, the second data is an inverse of the first data; and in another embodiment, the second data is random data, uniformly distributed, data or same data. Finally, in step 84B, the word line WLn, which fails the data reading in step 81B, of the flash memory is read again.

FIG. 9A and FIG. 9B show exemplary threshold voltage distributions without using the pre-verify voltage. Specifically, as shown in FIG. 9A, the high-bit page on word line WLn+1 is programmed with specific data, e.g., inverse data, that is capable of improving the coupling effect on the preceding word line WLn, assumed being not the last word line of a physical block, as shown in FIG. 9B. In case that the word line WLn is the last word line of the physical block, the high-bit page on word line WLn-1 is programmed instead.

FIG. 9C and FIG. 9D show some other exemplary threshold voltage distributions without using the pre-verify voltage. The VT distributions of FIGS. 9C and 9D are similar to those of FIGS. 9A and 9B, with the distinctness that the high-bit page on word line WLn+1 is programmed with random data. The modified embodiment according to FIGS. 9C and 9D may improve the coupling effect but with performance not good as that according to FIGS. 9A and 9B.

FIG. 10 shows a flow diagram of a method of programming a multi-bit per cell non-volatile memory for improving coupling effect according to a third embodiment of the present invention. Specifically, in step 101, data reading fails on a current word line WLn of the flash memory when the data cannot pass an error control. Subsequently, in step 102, the flash memory is read to obtain a first data of a most-significant-bit (MSB) page (e.g., high-bit page) on at least one neighbor word line. In the embodiment, the neighbor word line is the succeeding word line WLn+1 if the current word

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line WLn is not the last word line of a physical block; otherwise, the neighbor word line is the preceding word line WLn-1. Afterwards, in step 103, the high-bit page on the at least one neighbor word line WLn+1/WLn-1 is secondly programmed with a second data that is different from the first data. In one embodiment, the second data is an inverse of the first data; and in another embodiment, the second data is random data, uniformly distributed data or same data. Finally, in step 104, the word line WLn, which fails the data reading in step 101, of the flash memory is read again.

Although specific embodiments have been illustrated and described, it will be appreciated by those skilled in the art that various modifications may be made without departing from the scope of the present invention, which is intended to be limited solely by the appended claims.

What is claimed is:

1. A method of programming a multi-bit per cell non-volatile memory, comprising:
  - reading to obtain a first data of a most-significant-bit (MSB) page on a current word line that succeeds in data reading, wherein the current word line follows at least one preceding word line on which data reading fails;
  - setting at least one reference voltage; and
  - secondly programming the MSB page on the current word line with a second data according to the reference voltage, the second data being different from the first data.
2. The method of claim 1, wherein the non-volatile memory is a flash memory, a phase change memory (PCM) or an electrically erasable programmable read-only memory (EEPROM).
3. The method of claim 1, wherein the second data is an inverse of the first data.
4. The method of claim 1, wherein the reference voltage is a pre-verify voltage.
5. The method of claim 1, after the secondly programming step, further comprising a step of re-reading the preceding word line.
6. The method of claim 5, before re-reading the preceding word line, further comprising a step of resetting the reference voltage.
7. The method of claim 1, wherein the reference voltage is reset to a value of the reference voltage prior the setting step.
8. The method of claim 1, wherein the current word line and the preceding word line are neighboring to each other.
9. The method of claim 5, wherein the at least one preceding word line comprises a plurality of preceding word lines, and the setting step, the secondly programming step and the re-reading step are performed on each of the preceding word lines and its following adjacent word line, wherein the preceding word lines are successively performed from a last one toward a first one of the preceding word lines.

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